CIGUATERA IN THE FRENCH WEST INDIES

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Ciguatera fish poisoning was investigated on the Island of Saint-Barthelemy, Leeward Islands, Caribbean Sea, from 1979 to 1989. Clinical features include gastrointestinal and neurological disorders. 440 fish caught in fish-pots or by hook and line were checked by mouse and chicken bioassays. Jacks (*Caranx* spp.) and barracudas were highly ciguatoxic. Weight and toxicity were not correlated except for the most toxic species *Caranx latus*. Small carnivorous fishes classified as invertebrate feeders are likely involved in the transfer of ciguatoxin in the food chain since they contained significant levels of toxin. Herbivores (e.g. surgeonfishes or parrotfishes) which are not locally implicated in ciguatera, contained sometimes low levels of ciguatoxin. *Gambierdiscus toxicus* occurred in coastal waters of Saint Barthelemy but this species may not directly produce ciguatoxin.

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In the Caribbean, ciguatera poisoning is known from the Bahamas (Pesty,1975) to Martinique (Menger,1979) including Florida (Lawrence et al.,1980) Cuba (Bagnis,1979a) and Puerto Rico (Gilman,1942; Payne & Payne,1977) with a higher incidence in small Islands such as the Saintes, the Virgin Islands (Czernichow et al.,1984; Hanno,1981; Morris et al.,1982) and the Leeward Islands (Morice,1965). One of the Leeward Islands, Saint Barthelemy, is a small (c.25km), arid (without river or spring), tropical Island at 17°55'N, 62°50'W (Fig.1). The 3 adjacent islands of Saint Barthelemy, Saint Martin and Anguilla are surrounded by a wide shelf (max. depth 60m), with fringing reefs which continue across the shelf. These submerged reefs often form scattered coral-shoals 10–20m underwater. At the edge of the open sea the shelf falls abruptly to >200m. This coral reef ecosystem shelters a great variety of reef fishes (Vernoux et al.,1988).

Laboratory research on ciguatera was initiated in this area in the 1980's. It was shown that in fish the poison is lipid-soluble and quite similar to ciguatoxin isolated in the Pacific (Vernoux et al.,1982; Hoffman et al.,1983). Heterogencity of ciguatoxins extracted from viscera or flesh of Caribbean fish was also demonstrated (Vernoux & Abbad el Andaloussi,1986) and confirmed (Vernoux & Tahla,1989; Gamboa et al.,1990). *Gambierdiscus toxicus* (Bergman & Alam,1981; Besada et al.,1982) was suspected as the ciguatoxin elaborator and as the producer of maitotoxin (Miller et al.,1984). A study of ciguatera poisoning and occurrence of ciguatoxins in fish was carried out on Saint Barthelemy. Results are presented here, together with results from experiments with *G. toxicus* sampled at Tahiti in 1976 (in Dr. Bagnis's laboratory).

MATERIAL AND METHODS

Fish collected at numerous locations on Saint Barthelemy between 1979 and 1989 were identified from Stokes (1980). Most were caught in fish traps on the sea bottom (depth: 30-50m) within the reef habitat. King mackerel (*Scomberomorus cavalla*) and cero (*Scomberomorus regalis*) were collected by trolling, and greater amberjack (*Seriola dumerili*), black jack (*Caranx lugubris*) and african pompano (*Alectis crinitus*) by hook and line. Whole animals or separated tissues were frozen at –20°C for transport to the laboratory and stored until processed.

Lipid-soluble residues (LR) were prepared from flesh or viscera by a routine acetone or methanol method, respectively (Vernoux et al.,1985a). For the qualitative testing, fish liver or LR were fed to chicks as reported elsewhere (Vernoux et al.,1985b; Vernoux & Lahlou,1986). For quantitative testing a mouse bioassay was used (Vernoux et al.,1985a). The toxin concentration was expressed in Mouse Units gram per gram of tissue (MUg/g), where 1 MUg is the weight-specific minimum lethal dose (1MUg=1MU/20). Fish was assumed to be ciguatoxic when typical symptoms of ciguatera (Vernoux, this memoir) were observed in both chick and mouse.

For experiments in Tahiti in 1975 and 1976, a mixture of algae and detritus was scraped from the surface of dead corals collected at the Gam-

FIG.1. The Caribbean region.

bier Islands. This mixture was fractionated by hand according to size and, then by successive passes through sieves of different mesh sizes (Blutex Nylon: 85µm, 36µm and 10µm). Vortex shaking helped to separate associated organisms. Our routine acetone method was used to extract ciguatoxin in each biodetritus fraction. Remaining dry organic matter was treated with boiling methanol (Yasumoto & Endo,1973) to extract the maitotoxin. This allowed a separation of ciguatoxin (CTX) and maitotoxin (MTX) with little reciprocal contamination, since maitotoxin is poorly soluble in acetone (Yasumoto et al., 1976). These toxins were identified by symptomatology induced in mice and by their chromatographic behaviour on a silicic acid column. For analysing toxins in the gut contents of herbivorous fish the method of Yasumoto et al. (1977a) was used.

Analysis of variance (ANOVA) was done using SPSS-PC software. A non-parametric ANOVA K-W test was also used in parallel.

RESULTS

Epidemiology

With the help of some local physicians, fish poisoning was surveyed at Saint Barthelemy (3000 inhabitants). 10–30 cases were identified per year either from consultations or from patients treated at the hospital. Generally they were fishermen or tourists having consumed small jacks, big mackerels, snappers or seabass. In some cases, poisoning was induced after a second meal of the same fish. Patients complained of sensitivity disturbances (painful tingling about the mouth and throat, hot and cold reversal) nausea and vomiting, abdominal pain, diarrhoea, myalgia, weakness and hypotension. Visual disturbances (blurred vision) and persistent itching were also noted. After symptomatic therapy, complete recovery occurred after a few days, weeks or months. After a primary poisoning some individuals develop a fish feeding allergy and cannot eat any fresh or canned fish. Toxin analysis of fishes implicated in these ciguatera outbreaks revealed ciguatoxins at >1MUg/g of flesh.

Distribution of Toxicity

During the course of this study we observed that fish only contained toxin in their flesh if their livers were also toxic. Furthermore, ciguatoxin concentration was always higher in viscera than in flesh (at least twice as toxic).

The most toxic species (1–10 in Table 1) are large piscivorous species except for *A. afer* which is a small (<300g) invertebrate feeder.

Intermediate toxicity was detected in species 11–15 (Table 1). Lower toxicity was present in other species (16–30 in Table 1). The above classes include small species (<500g) such as *M. martinicus*, *P. arenatus*, *B. rufus* and *H. radiatus* and *M. plumieri* (<1kg) which feed mainly on benthic invertebrates; these species can be more toxic than some larger piscivorous species. Only one species of herbivorous fish, the ocean surgeonfish (29 in Table 1), had low toxicity. No toxicity was found in other herbivorous fish (31–35 in Table 1). The longjaw squirrelfish (36 in Table 1), a specific crustacean feeder, was not toxic.

Statistical analysis of variance of individual toxicity for species 1–11 (Table 1) (independent of weight) indicated that the means were significantly different ($p<0.01$) for the 11 species group unless *C. latus* and *C. bartholomaei* were removed from this group. Without *C. latus*, the F test was not significant ($p=0.13$) but the K-W test was significant ($p=0.04$). This discrepancy can be explained by the difference in size between the *C. bartholomaei* sample (n=45) and the other

TABLE 1. Flesh ciguatoxicity in various fish species from Saint Barthelemy Island: results presented in decreasing order according to toxicity.

No.	Species	Specimen weight	TOXIN CONCENTRATION IN MUg/G OF FLESH							
			<0.05	0.05–0.49	0.5–0.99	1–1.49	1.5–1.99	2–2.99	3–5	>10
1	*Seriola dumerili*	6–29			1				1	
2	*Caranx latus*	1.3–6		1	8	8	1	2	4	
3	*Caranx ruber*	0.75–2.3		4		1		1		
4	*Caranx bartholomaei*	0.75–4.8		12	14	12	4	2	1	
5	*Alectis crinitus*	3.3–12		5			1	1		
6	*Sphyraena barracuda*	3–10		2	2	1				1
7	*Epinephelus morio*	6.5–8		2	1			1		
8	*Alphestes afer*	0.1–0.25		(16)(11)(12)(2)	(6)	(2)				
9	*Scomberomorus cavalla*	15–20			1	3				
10	*Scomberomorus regalis*	3–4	1	1		1				
11	*Gymnothorax funebris*	3.5–14.5		6	2					
12	*Malacanthus plumieri*	0.3–0.6		(5)(20)(5)(4)(6)(4)(2)(12)	(5)(15)					
13	*Lutjanus jocu*	1.7–2.2		1	2					
14	*Lutjanus griseus*	1.9–2		2	1					
15	*Lutjanus buccanella*	0.3–1.5		(3)1(2)	(2)					
16	*Priacanthus arenatus*	0.4–0.6		(3)(2)						
17	*Bodianus rufus*	0.2–0.4		(2)(15)(12)						
18	*Halichoeres radiatus*	0.5–1		(4)(3)						
19	*Gymnothorax moringa*	1.5–2		2						
20	*Mulloidichtys martinicus*	0.2–0.4		(20)(20)						
21	*Mycteroperca venenosa*	3.2–4.5		3						
22	*Caranx lugubris*	2.5		1						
23	*Lutjanus analis*	4–5		2						
24	*Seriola rivoliana*	2.7–4.5		2						
25	*Mycteroperca tigris*	0.7		(2)						
26	*Epinephalus guttatus*	0.7–0.9		(3)						
27	*Epinephalus adscension*	0.5–0.7		(4)						
28	*Calamus calamus*	0.2–0.4		(6)						
29	*Acanthurus bahianus*	0.05–0.15		(37)(6)						
30	*Balistes vetula*	1.5–2	1	1						
31	*Acanthurus chirurgus*	0.2–0.4	(3)(4)(7)							
32	*Acanthurus coeruleus*	0.2–0.4	(10)							
33	*Scarus coeruleus*	2	1							
34	*Scarus vetula*	0.6	(2)							
35	*Sparisoma viride*	1	1							
36	*Holocentrus ascensionis*	0.1–0.2	(11)							

Specimens were tested individually except where indicated by brackets in which case the number of pooled specimens is given.

samples (n<10). *Caranx latus* had the highest mean toxicity of species examined, suggesting that it is the most dangerous species at Saint Barthelemy.

The relationship between individual toxicity and weight was investigated within each of nine species for which n>2; the smooth curves (Fig.3) were fitted with the linear regression model:

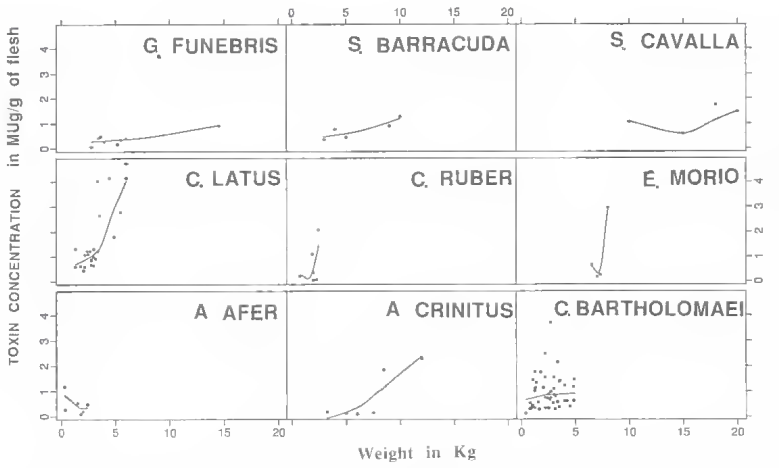

FIG.2. Relation between weight and toxicity for some toxic fish species.

toxicity = $\beta_0 + \beta_1$ weight +E,

where toxicity is in MUg/g and weight is in kg. A significant linear correlation between toxicity and weight was found ($\beta_1/0$) only for *C. latus* ($p<001$; β_0=-0.85502; β_1= 0.79673) and *A. crinitus* ($p=.014$; β_0=-1.31314; β_1=0.29066).

USE OF BIO-INDICATORS

Since jacks occupy the upper part of the ciguatera food chain, we chose *C. bartholomaei* and *C. latus* adults (>1kg) to investigate the degrce of bioaccumulation of ciguatoxin per year. From 1979–1985 the median concentration per year of ciguatoxin in their flesh (n=62) was stable around 1MUg/g of flesh. During the same period other bioindicator species such as *M. plumieri* and *A. afer* (benthic fishes) which were thought to feed directly on the ciguatoxin producers were also studied. Their toxicity level per year was constantly 0.2–0.6MUg/g of flesh. So the amount of toxins in the food chain at Saint Barthelemy appeared stable over this period. Nevertheless, in the last years of this study toxicity of *C. latus* was 3–4 times higher (n=10), but no change was found in the toxicity of *C. bartholomaei* (n=15).

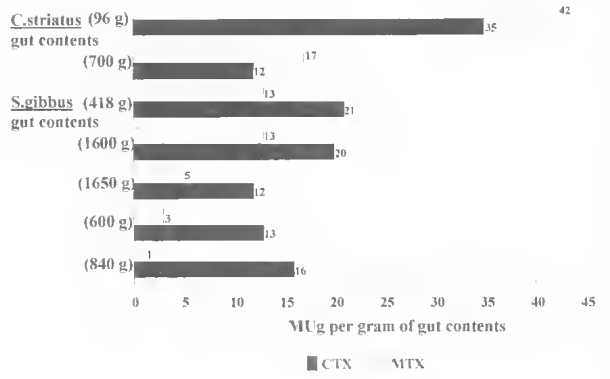

FIG.3. Distribution of toxins in gut contents of surgeonfish *C. striatus* and parrotfish *S. gibbus* caught at the same place in the Gambier Islands.

DISTRIBUTION OF TOXINS AND *G. TOXICUS* IN GUT CONTENTS OF HERBIVOROUS FISHES AND IN CORAL SAMPLES

Extracts of coral samples collected at Saint Barthelemy blanketed with algae did not contain detectable ciguatoxin, even though *G. toxicus* was present in low numbers on these samples.

The maitotoxin and ciguatoxin analysis of gut contents of herbivorous fish, obtained in 1975–1976 from French Polynesia (Fig.3) shows that materials ingested by parrotfish *S. gibbus* or surgeonfish *C. striatus* contained ciguatoxin (fat soluble toxin) and maitotoxin (acetone precipitated toxin). Furthermore, the concentration of ciguatoxin in gut contents of parrotfish was always higher than that of maitotoxin, whereas the ratio of the two toxins was reversed in the gut contents of the surgeonfish. Thus ciguatoxin level appears unrelated to maitotoxin level.

CTX content (in MUg) is quantitatively dominant in scraped coral substrate and in the fraction >85μm (=algae+detritus), four times as much as in the *G. toxicus* fraction (Fig.4A). Attempts to remove CTX from coral substrate by scraping in the presence of a low pressure spray of water were unsuccessful: 30–60% of total CTX content remained attached to the coral substrate (3 experiments). With crude material (not frozen) results were

similar. The MTX content was well correlated with *G. toxicus* (which accumulated in 36–85μm fraction) and the ratio of MTX to CTX was >1 as it was for the gut toxin contents of *C. striatus*.

Specific CTX content (in MUg/g of dry matter) seems to reside not only with the *G. toxicus* fraction but also on the other size fractions, particularly the fraction <36μm (particles + washing water) (Fig.4b).

G. toxicus thecal structure can be extremely resistant to different conditions: freezing, water dilution, acetone extraction and ultra-turrax sonication.

DISCUSSION

The involvement of fat soluble ciguatoxins in ciguatera in the Caribbean has been confirmed by chemical studies on the toxins in *C. bartholomaei* (Vernoux et al.,1982), *B. rufus*, *M. martinicus*, *M. plumieri*, *E. morio*, *G. funebris*, *S. barracuda*, *S. cavalla*, *S. dumerili* (Vernoux & Abbad,1986), and *A. crinitus*, *C. latus* (Vernoux & Talha,1989). In the Virgin Islands, similar species were clinically found to cause ciguatera poisoning (Brody, 1971; Morris et al.,1982; Englcberg et al.,1983) and ciguatoxin from *Lutjanus buccanella* has been well documented (Hoffman et al.,1983).

At Saint Barthelemy the same species of fish were ciguatoxic as in the Pacific (Randall,1958; Halstead,1978). Nevertheless, jacks are much more toxic in the Caribbean (Arcisz,1950) than in the Pacific Ocean (*Caranx ignobilis* was the only species suspected in the Pacific by Bagnis (1981)). The importance of feeders on small benthic invertebrate feeders in the ciguatera food chain at Saint Barthelemy is worth pointing out since this suggests that ciguatera transmission begins primarily at the invertebrate level. Invertebrates appear to be less important in the Pacific area, though some feeders on invertebrates, such as *Lethrinus kallopterus* at the Marshall Islands (Randall,1980), *Cheilinus undulatus* at Tahiti (Bagnis,1968) and other Lethrinidae at New Caledonia (Bagnis,1979a) are ciguatoxic.

In the French West Indies all ciguateric species were shore fish associated with reefs. With the exception of two semi-pelagic open water species, the king mackerel and cero, they were bottom dwelling species generally found at a depth of <50m (>100m for black jack and greater amberjack). Ciguatoxins are therefore well correlated with the benthic fish. Further illustration is provided by *Caranx ruber* which is dangerous at Saint Barthelemy when caught in fish traps

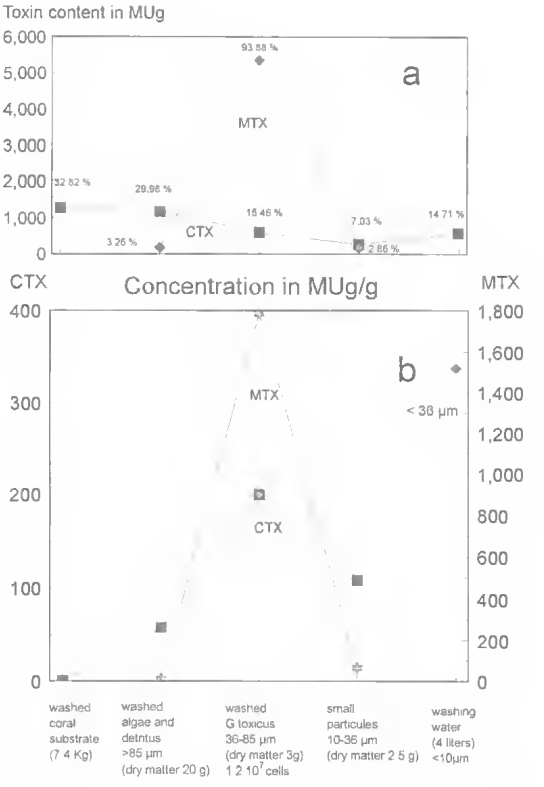

FIG. 4. Distribution of toxins MTX and CTX in fractionated material from the Gambier Islands either considering total toxin content (a) or toxin concentration (b).

(sedentary individuals) but not in nets (migrating shoals of fish).

Unlike the Pacific, at Saint Barthelemy herbivorous fish are regularly consumed without suspicion. Similar observations have been reported in other areas of the Caribbean (Bagnis 1979a; Czernichow et al.,1984) in New Caledonia (Bagnis,1979b) and in the Indian Ocean (Lebeau & Telmar,1978). Nevertheless detectable ciguatoxicity in the surgeonfish *A. bahianus* indicates that low (subsymptomatic) ciguatoxin levels may be present in some Caribbean herbivorous fish species, illustrating that fish edibility depends on toxin level as already described (Bagnis & Vernoux,1975). Here we cannot exclude the possibility that ciguatoxin is present in the other herbivorous fishes, though ciguatoxin levels are probably (extremely) low. The higher toxicity of *A. bahianus* suggests a different diet. We studied 3 Caribbean surgeonfishes (Stokes,1980; Randall,1983) that have different feeding habits (Randall,1967): *A.*

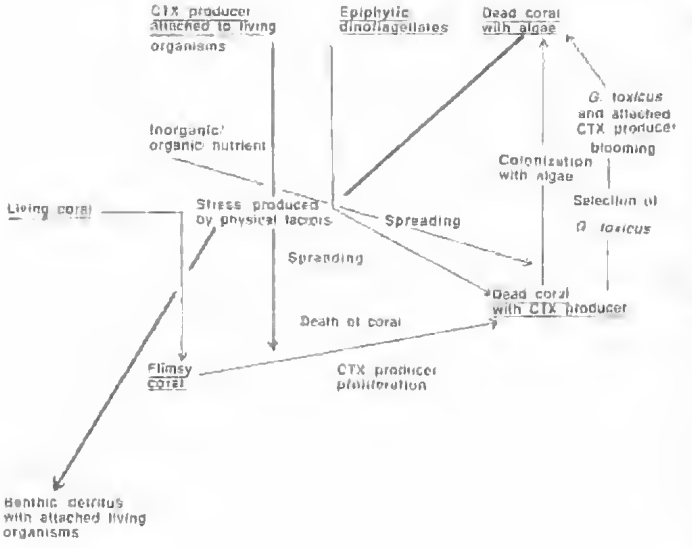

FIG. 5. A proposed mechanism for the initiation of CTX producer proliferation.

chirurgus and *A. bahianus* has a thick walled gizzard-like stomach and ingests inorganic sediment (sand, small shells etc.) with the algae they crop from solid substrata (especially *A. bahianus*) (in Randall,1967; and personal observations); and *A. coeruleus* has a thin walled stomach in which we have observed a higher content of green algae and it does not usually ingest sand. The former are therefore grazers whereas the latter is a browser following the definition of Lobel (1981). In the West Indies, parrotfishes are also grazers that feed mainly on algae attached to dead coral (Randall,1967), except for large *Sparisoma viride* and occasionally large *Scarus vetula* which graze on live coral (Frydl,1979). Taking into account these feeding habits and the corresponding toxicity results, we deduce that the source of the toxin in the food could be an organism linked to bottom detritus. The ciguatoxin producer *G. toxicus*, found on dead coral (Bagnis et al.,1980) and closely associated with reef sediments or with macroalgae (Taylor,1979; Yasumoto et al.,1979) may be the ciguatoxin-producer at Saint barthelemy. This conclusion is consistent with the presence of *G. toxicus* (Bagnis,1981; Besada et al.,1982; Bourdeau & Durand-Clement,1991) and with previous studies (Yasumoto et al., 1977b; Bagnis et al.,1980) which have implicated *G. toxicus* as the ciguatera produced in the Pacific. Nevertheless, the somewhat conflicting results obtained in the study of scraped coral and discussion concerning ingested toxins in gut contents of herbivorous fish at Tahiti have not previously been considered.

Chanteau (1978) studied scraped coral as well as other fractions for toxicity. She obtained toxin partitioning results similar to ours, even though scraping was practised with a metallic brush, i.e. MTX content was highly correlated with the *G. toxicus* containing fraction and <10% of total MTX was present in scraped coral substrate, and in this substrate the proportion of MTX to CTX were inverted (<1). These observations and ours demonstrated that: MTX is a *G. toxicus* marker, especially since it is never excreted out of the dinoflagellate (Yasumoto et al.,1979b). However, CTX contamination level was independent of the amount of *G. toxicus* in these studies. This latter statement was corroborated by analysis of toxins in the gut contents of herbivorous fish: our results and those of others (Yasumoto et al.,1975; Yasumoto et al. 1977a) showed that the relative proportions of MTX and CTX are inverted in surgeonfish (*C. striatus)* compared with parrotfish (*S. gibbus)* caught in the same area. The difference in proportion corresponds to the difference in their feeding habits: the former is a browser which ingests chlorophyll-bearing material (10%) as well as detritus and numerous *G. toxicus* were found in its stomach and gut contents, while the parrotfish is a coral feeder exclusively (103–260µg of algae/100g of ingested sample according to Yasumoto et al. (1977a) and no *G. toxicus* was visible in its stomach or gut contents (Vernoux,1981). Thus ciguatoxin producer could be associated also with living coral (perhaps the zooxanthellae?). Bagnis et al. (1980) stated that they could not find any indication that CTX (or MTX) was excreted into the culture medium, while Shimizu et al., (1982) and Campbell et al. (1987) using fluorescence labelled sheep anti-ciguatoxin antibody both found that the outer wall of a certain percentage of *G. toxicus* contained ciguatoxin and/or ciguatoxin-like compounds. Thus the ciguatoxin producer could be a very small organism dependent (or not) on certain epiphytic dinoflagellates such as *G. toxicus* and perhaps zooxanthellae. The findings that (i) ciguatoxin inhibits cellular multiplication of unicellular marine algae (Durand et al.,1985), (ii) coral death often seems necessary to induce

ciguatera production (Bagnis,1981), (iii) dead coral provides new surfaces for dinoflagellates implicated in ciguatera fish poisoning (Kohler & Kohler,1992) and (iv) the presence of CTX in dead corals with *G. toxicus* together suggest that the ciguatoxin producer could contribute to the death of living coral which could in turn enhance *G. toxicus* proliferation (Fig.5).

LITERATURE CITED

ARCISZ, W. 1950. Ciguatera: tropical fish poisoning. U.S. Fish and Wild Special Science Reprint 27: 23.

BAGNIS, R. 1968. Clinical aspects of ciguatera (fish poisoning) in French Polynesia. Hawai Medical Journal 28: 25–28.

BAGNIS, R. & VERNOUX, J.P. 1975. Ciguatoxine et poissons de récifs comestibles. Bulletin de la Société de Pathologie exotique 68: 320–325.

BAGNIS, R. 1979a. Données récentes concernant quelques aspects biologiques de la ciguatera aux Antilles, Caraïbes Médical 2: 30–36.

BAGNIS, R. 1979b. Ciguatera fish poisoning in New Caledonia. Clinical and epidemiological aspects. Revue. Epidémiologique. Santé Publique 27: 17–29.

BAGNIS, R., CHANTEAU, S., CHUNGUE, E., HURTEL, J.M., YASUMOTO, T. & INOUE, A. 1980. Origins of ciguatera fish poisoning; a new dinoflagellte, *Gambierdiscus toxicus* Adachi and Fukuyo, definitively involved as a casual agent. Toxicon 18: 199–208.

BAGNIS, R. 1981. Etude morphologique, biologique, toxicologique et écologique de l'agent causal princeps de la ciguatera, le P éridinien *Gambierdiscus toxicus*. Thése Sciences, 180p. Université de Bordeaux II.

BERGMANN, J.S. & ALAM, M. 1981. On the toxicity of the ciguatera producing dinoflagellte *Gambierdiscus toxicus* Adachi and Fukuyo, isolated from the Florida Keys. Journal of Environmental Health Science 16: 493—500.

BESADA, E.G., LOEBLICH, L.A. & LOEBLICH, A.R. 1982. Observations on tropical benthic dinoflagellates from ciguatera endemic areas: Coolia, Gambierdiscus and Ostreopsis. Bulletin of the Marine Science 32: 723–735.

BOURDEAU, P. & DURAND-CLEMENT, M. 1991. Ichtyosarcotoxisme de type ciguatera: étude écotoxicologique et morphologique de *Gambierdiscus toxicus* aux Antilles Françaises (St Barthelemy). In J.M. Fremy, (ed.), 'Proceedings of symposium on marine biotoxins, 30-31 Janvier 1991'. (CNEVA).

BRODY, R.W. 1971. Fish poisoning in the Eastern Caribbean. Proceeding of Gulf and Caribbean Fisheries Institute 24: 100–116.

CAMPBELL, B., NAKAGAWA, L.K., KOBAYASHI, M.N. & HOKAMA, Y. 1987. *Gambierdiscus toxicus* in gut content on the Surgeonfish (*Ctenochaetus strigosus* (Herbivore) and its relation to toxicity. Toxicon 25: 1125–1127.

CHANTEAU, S. 1978. Rôle d'un dinoflagellé benthique dans la biogenèse de la ciguatera. Ph.D Thesis, University of Clermont Ferrand II, 63p.

CZERNICHOW, P., DROY, J.M., EZELIN, F. & LEROY, J. 1984. La ciguatera aux îles Saintes (Guadeloupe): maladie transmise par les poissons. La Presse Médicale 13: 222.

ENGLEBERG, N.C., MORRIS, J.G. Jr., LEWIS, J., McMILLAN, J.P., POLLARD, R.A. & BLAKE, P.A. 1983. Ciguatera fish poisoning: a major common-source outbreak in the U.S. Virgin Islands. Annals of Internal Medecine 98: 336–337.

FRYDL, P. 1979. The effect of parrotfish (Scaridae) on coral in Barbados (W.I.). International Review of Ges. and Hydrobiology. 64: 737–748.

GAMBOA, P.M., PARK, D.L., FREMY, J.M. 1990. Extraction and purification of toxic fractions from barracuda (*Sphyraena barracuda*) implicated in ciguatera poisoning. Presented at 3rd conference on Ciguatera, April 30 – May 4, Lajac, Puerto Rico.

GILMAN, R.L. 1942. A review of fish poisoning in the Puerto-Rico, Virgin Islands area. U.S. Naval Medical Bulletin 40: 19–27.

HANNO, W.A. 1981. Ciguatera fish poisoning in the Virgin Islands. Journal of American Medical Association 245(5): 464.

HALSTEAD, B.W. 1978. 'Poisonous and venomous marine animals of the World' 1043p. (Princeton University Press: Darwin, N.J.).

HOFFMAN, P.A., GRANADE, H.R. & McMILLAN, J.P. 1983. The mouse ciguatoxin bioassay; a dose response curve and symptomatology analysis. Toxicon 21: 363–369.

KOHLER, S. & KOHLER, C. 1992. Dead bleached coral provides new surfaces for dinoflagellates, implicated in ciguatera fish poisonings. Environmental Biology of Fishes 35: 413– 416.

LAWRENCE, D.N., ENRIQUEZ, M.B., LUMISH, R.M. & MACEO, A. 1980. Ciguatera fish poisoning in Miami. Journal of American Medical Association 244: 254–258.

LEBEAU, A. & TELMAR, J.M. 1978. La ciguatera dans l'Océan Indien. Revue Travaux Institut Pêches Maritimes 42: 325–345.

LOBEL, P.S. 1979. Trophic biology of herbivorous reef fishes: alimentary pH and digestive capabilities. Journal of Fish Biology 19: 365–397.

MENGER, D. 1979. Ichtyosarcotoxisme: à propos de 5 cas observés dans les Antilles Françaises (Martinique). Thèse Médecine, 86p., Faculté de Médecine de Grenoble I.

MILLER, D.M., DICKEY, R.W. & TINDALL, D.R. 1984. Lipid extracted from a dinoflagellate *Gambierdiscus toxicus*. American Chemical Society Symposium Series 262: 241–255.

MORICE, J. 1965. Catalogue descriptif des poissons

vénéneux du banc de Saint-Barthélémy. Revue Travaux Institut Pêches Maritimes 29: 4–130.

MORRIS, J.G.Jr., LEWIN, P., SMITH, C.W., BLAKE, P.A. & SCHNEIDER, R. 1982. Ciguatera fish poisoning: epidemiology of the disease on Saint Thomas, U.S. Virgin Islands. American Journal of Tropical Medicine and Hygiene 31: 574– 578.

PAYNE, C.A. & PAYNE, S.N. 1977. Ciguatera in Puerto Rico and the Virgin Islands (letter). New England Journal of Medicine 296: 949–950.

PESTY, H. 1975. Mer des Caraïbes, alerte à la ciguatera - Semaine des Hôpitaux, Supplément aux informations du 26 Mai, pp.10–12.

RANDALL, J.E. 1958. A review of ciguatera, tropical fish poisoning, with a tentative explanation of its cause. Bulletin of Marine Science Gulf Carribbean 8: 236–267.

RANDALL, J.E. 1967. Food habits of reef fishes of the West Indies. Studies in Tropical Oceanography 5: 665–847.

RANDALL, J.E. 1980. A survey of ciguatera at Enewetak and Bikini, Marshall Islands with notes on the systematics and food habits of ciguatoxic fishes. Fish Bulletin 78: 201– 249.

RANDALL, J.E. 1983. 'Carribbean reef fishes' (revised ed.), 350p. (T.F.H. Publications: New Jersey).

SHIMIZU, Y., SHIMIZU, H., SCHEUER, P.J., HOKAMA, Y., OYAMA, M. & MIYAHARA, J.T. 1982. *Gambierdiscus toxicus*, a ciguatera-causing dinoflagellate from Hawaii. Bulletin of the Japanese Society of Scientific Fisheries 48(6): 811–813.

STOKES, F.J. 1980. 'Handguide to the coral reef fishes of the Carribbean', 160p. (Wm. Collins Sons: Melbourne).

TAYLOR, F.J.R. 1979. A description of the benthic dinoflagellate associated with maitotoxin and ciguatoxin including observations on Hawaiian material. Pp.71–76. In Taylor, D.L. & Seliger, H.H. (eds) 'Toxic dinoflagellate blooms' (Elsevier: Amsterdam).

VERNOUX, J.P. 1981. L'ichtyosarcotoxisme de type ciguatera aux Antilles et en Polynésie Française: tests de ciguatoxicité et chaîne trophique ciguatérigène. Ph.D. Thesis, 140 p., Université de Bordeaux.

VERNOUX, J.P., GAIGN, M., RIYECHE, N., TAGMOUTI, R., MAGRAS, L.Ph. & NOLEN, J. 1982. Demonstration of a liposoluble ciguateric toxin in *Caranx bartholomaei* caught in the French West Indies. Biochimie 64: 933–939.

VERNOUX, J.P., LAHLOU, N., ABBAD EL ANDALOUSSI, S., RIYECHE, N. & MAGRAS, L.Ph. 1985a. A study of the distribution of ciguatoxin in individual caribbean fish. Acta Tropica 42: 225–233.

VERNOUX, J.P., LAHLOU, N., MAGRAS, L.Ph. & GREAUX, J.B. 1985b. Chick feeding test: a simple system to detect ciguatoxin. Acta Tropica 42: 235–240.

VERNOUX, J.P. & ABBAD EL ANDALOUSSI, S. 1986. Heterogeneity of ciguatoxins extracted from fish caught at the coast of the French Antilles. Biochimie 68: 287–291.

VERNOUX, J.P. & LAHLOU, N. 1986. Contrôle biologique de la ciguatoxine chez le poussin: analyse des symptômes induits et de la toxicité d'extraits de poissons ciguatoxiques de l'île de Saint-Barthélémy. Bulletin de la Société de Pathologie exotique 79: 140–147.

VERNOUX, J.P., MAGRAS, M. & MAGRAS, Ph. 1988. 'Coral fishes of the West Indies', 128p. (Latanier: Paris).

VERNOUX, J.P. & TALHA, F. 1989. Fractionation and purification of some muscular and visceral ciguatoxins extracted from caribbean fish. Comparative biochemistry and Physiology 94B(3): 499–504.

YASUMOTO, T., BAGNIS, R., VERNOUX, J.P. & CHUNGUE, E. 1975. Toxins in the viscera and ingested materials of herbivorous fish and molluscs linked to coral reefs. Annual report for the South Pacific Commission 1975; 407.

YASUMOTO, T., NAKAJIMA, I., CHUNGUE, E. & BAGNIS, R. 1977a. Toxins in the gut contents of a parrotfish. Bulletin of the Japanese Society of Scientific Fisheries 43: 69–74.

YASUMOTO, T., BAGNIS, R., THEVENIN, S. & CARGON, M. 1977b. A survey of comparative toxicity in the food chain of ciguatera. Bulletin of the Japanese Society of Scientific Fisheries 43: 1015–1019.

YASUMOTO, T., INOUE, A. & BAGNIS, R. 1979. Ecological survey of a toxic dinoflagellate associated with ciguatera. Pp.221–224. In Taylor, D.L. & Seliger, H.H. (eds), 'Toxic dinoflagellate blooms'. (Elsevier: Amsterdam).

YASMOTO, T., NAKAJIMA, I., OSHIMA, Y. & BAGNIS, R. 1979b. A new toxic dinoflagellate found in association with ciguatera. Pp. 65–70. In Taylor, D.L. & Seliger, H.H. (eds), 'Toxic dinoflagellate blooms'. (Elsevier: Amsterdam).

YASUMOTO, T. & ENDO, M. 1973. Toxicity study on a marine snail *Turbo argyrostoma*. I. Presence of two sulfur containing amines in the acetone soluble fraction. Bulletin of Japanese Society of Scientific Fisheries 39: 1055–1061.

YASUMOTO, T., BAGNIS, R., VERNOUX, J.P. 1976. Toxicity of the surgeonfishes II: Properties of the principal water soluble toxin. Bulletin of the Japanese Society of Scientific Fisheries 43: 359-365.